Development of Screwdriver Bit Steel with High Hardness and Torque Value

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Screwdriver bits with higher hardness and torque values are necessary and beneficial for manufacturers to promote the sales of their products. Materials, heat treatment and the machining process are the three key factors affecting the properties of a screwdriver bit. In this study, a new steel was developed by alloy design, and further suitable heat treatment with quenching & tempering was applied to obtain the necessary properties. According to the results, the hardness of a screwdriver bit made by this newly developed steel is greater than HRC60, and the torque value of a screwdriver bit in the shape specification of length 100 mm, 1/4 in. hexagon, with Ph.2 tip is in the range around 228~248 kgf·cm.

1. INTRODUCTION

Screwdrivers are the most popular hand tools in our daily lives. Although the properties of current screwdriver bits have satisfied the requirement for general use by hand, the demand for screwdriver bits with higher hardness and higher torque values still have been proposed by screwdriver manufacturers to meet the requirement of the competitive business markets. Higher torque values can be obtained by achieving higher hardness and higher toughness simultaneously; however, higher hardness is usually accompanied by lower toughness. To manufacture a screwdriver bit with both higher hardness and torque, three key factors are crucial and should be taken into consideration: materials, heat treatment and the machining process. In the hand tool market, the most popular steel used for screwdriver bits is Cr-V steel, such as SAE6150 steel. The hardness of a screwdriver bit made by Cr-V steel is about HRC52 ±2, and the torque value is around 180~190 kgf·cm. With the evolution of steel development, S2 and SAE9254 (Si-Cr) steels are also applied to screwdriver bits by some manufacturers. Table 1 shows the properties of screwdriver bits made by these different steels. Comparing the screwdriver bits made by S2 steel with those made by SAE9254 steel, the former are harder owing to their higher carbon content but have lower torque values due to their lower toughness. Although the hardness of an S2 screwdriver bit can reach HRC60, this higher hardness will lead to it breaking in a brittle fracture. Such a type of fracture may cause eye damage from the broken brittle chips; therefore, the hardness of an S2 steel used for screwdriver bits should not be greater than HRC58. In this study, a new alloy steel for use in screwdriver bits was developed for advanced higher hardness and torque value, with hardness being greater than HRC60 and the torque value being in the range of 228~248 kgf·cm, for screwdriver bits in the shape specification of length 100 mm, 1/4 in. hex., Ph.2 tip.

Table 1 Properties of specific steels used for screwdriver bits

Steel	Hardness (HRC)	Torque Value (kgf·cm)
SAE6150 (Cr-V)	52±2	180~190
SAE9254 (Si-Cr)	56±0.5	220~240
S2	59±1	220
Newly developed steel	≧60	228~248

2. EXPERIMENTAL METHOD

2.1 Manufacturing Processing

The manufacturing process of a screwdriver bit is shown below:
As-rolled wire → Spherical annealing → Drawing → Tip machining → Heat treatment → Shot blasting → (Coating) → Properties test

2.2 Materials

The composition of the new steel was re-designed with reference to SEA6150, SAE9254 and S2 steels. Table 2 shows the main compositions of the current and the newly developed steels used for screwdriver bits. The starting steel in this study was smelted in a vacuum furnace and cast into an ingot with size of about 210 mm×210mm. It was then forged to the shape of 118 mm×118mm square billet size and further welded with S2 billet in the plant. As-rolled wire with a diameter 8 mm coil was milled in the China Steel Corporation (CSC) bar #2 mill plant, and spherical annealing treatment in accordance with the spherical annealing pattern of S2 steel was performed in Song Ho Industrial Co., Ltd. Figure 1 and Figure 2 show the spherical annealing pattern and microstructure respectively.

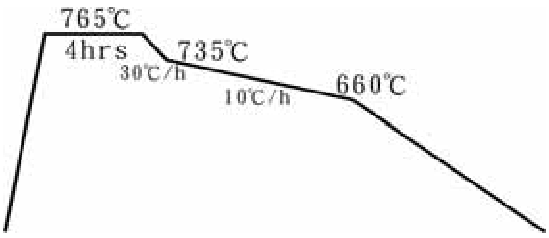

Fig. 1. Spherical annealing patent for the newly developed steel.

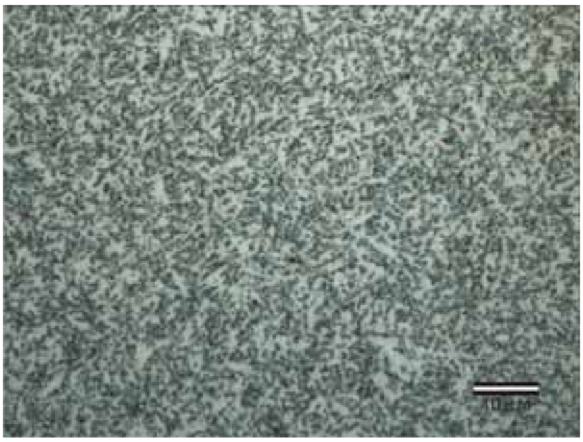

Fig. 2. Spherical annealing microstructure for the newly developed steel.

2.3 High Temperature Deformation Resistance Testing

Heat temperature deformation resistance testing was performed by Gleeble 1500 thermomechanical simulator. The differences for the high temperature deformation resistance between the newly developed steel and the S2 steel were examined and taken as reference. The results provided CSC bar #2 mill plant reference points for controlling and adjusting the power of the rod mill for this newly developed steel.

2.4 Dilatometer Detecting

Phase transformation points including Ac1, Ac3, Ms and TTT curve were examined by dilatometer. Those provided useful reference bases for subsequent heat treatment for this study.

2.5 Heat Treatment

To obtain the optimized properties of a screwdriver bit, spheroidized wire was adopted for subsequent heat treatment. Pieces of specimens were cut from spheroidized wire and held at different austenitizing temperatures vs. time, and then further oil quenched. Different austenitizing temperatures for this trial were set at 820℃, 840℃, 860℃, 880℃and 900℃, and the austenitizing periods were 5, 10, 15, 20, 30, 40 minutes, respectively, for each tested austenitizing temperature. The optimized austenitizing condition was adopted by the hardness curves of these testing samples.

The as-quenching specimen was brittle and not stable owing to its martensite structure. Tempering treatment must be done for higher toughness and to obtain the desired hardness. The specimens subjected to optimal austenitizing condition was treated then for tempering treatment. The range of tempering temperatures for this trial was set at 150℃~210℃, and specimen under test was held for 2 hours at each testing temperature. A hardness curve vs. tempering temperature was plotted, which provided the basis of the heat treatment of the newly developed steel for Yih Cheng Factory Co., Ltd.

2.6 Mechanical Properties

Hardness and torque value are two key mechanical properties for screwdriver bits. The former is usually identified by Rockwell Hardness test machine in HRC unit, while the latter is obtained under the torque machine

Table 2 Main compositions of specific steels used for screwdriver bits

Steel	C	Si	Mn	Ni	Cr	Mo	V	Nb
6150	0.50	0.20	0.80		0.95		0.20	
9254	0.54	1.40	0.70		0.70			
S2	0.67	1.20	0.50		0.25	0.45	0.17	
Newly	0.66	added	0.50	added	added	0.25	0.08	added

by the specimen in the shape specification of length 100 mm, 1/4 in. hex., Ph2 tip, screwdriver bit in Yih Cheng Factory Co., Ltd.. Figure 3 shows the profiles of Ph.2 tip of screwdriver bits before and after torsion testing.

Fig. 3. Profiles of Ph.2 tip of screwdriver bits before and after torsion testing.

2.7 Metallograph

The metallograph of the spherical annealing specimen was observed by optical microscopy (OM), and the heat treated samples, including as-quenching and as-tempering, were examined by scanning electron microscopy (SEM).

3. RESULTS

Figure 4 and Figure 5 show the phase transformation points and TTT curve of the newly developed steel measured by dilatometer, respectively. Fig. 4 shows that the Ac3 point is about 850℃ and that the Ms is around 220℃. These two transformation points give some hints on the required heat treatment for the newly developed steel. The austenitizing temperature must be greater than 850℃ and oil quenching temperature must be lower than 220℃. From TTT curve, shown in Fig. 5, a wide region of γ phase existed in the area on the left side of transformation starting line (left line) and above the Ms line. This implies that the hardenability of this newly developed steel is rather high, and the negative effect caused by high hardenability must be taken into consideration during the manufacturing processes, such as the rod/wire mill process and wire the shipping process.

S2 steel is infamous due to its high hardenability and high thermal deformation resistance among CSC wire products. Such wire products with high hardenability milled from billet must be taken good care of during the manufacturing process for each working stand. Cobble on the production line in the mill plant caused by high hardenability and high

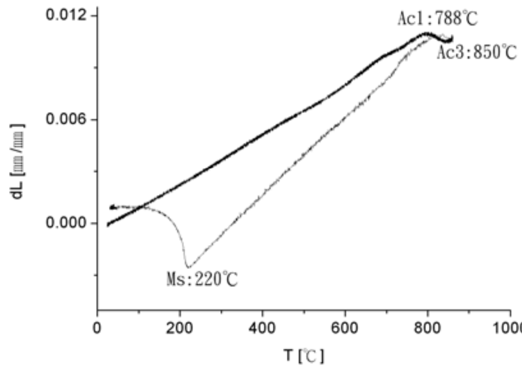

Fig. 4. Phase transformation point of the newly developed steel examined by dilatometer.

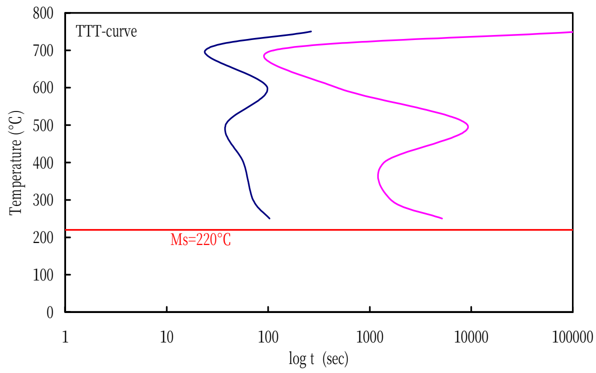

Fig. 5. TTT diagram for the newly developed steel.

thermal deformation resistance must be prevented. Figure 6 shows the high temperature deformation resistance curves for the newly developed steel and S2 steel. It shows that the high temperature deformation resistance of the newly developed steel is higher than that of S2 steel. Hence, the mill power of each stand for the newly developed steel wire mill must be increased for extra higher thermal deformation resistance compared with that for S2 steel wire mill. According to the past experience of S2 wire-making, spherical annealing treatment must be carried out not only to prevent the wire coil from accidental breakage during the storage or shipping period, but also to soften the rod coil to assist in the subsequent drawing process. The hardness of the spherical annealing wire is about HRB95 when it is drawn into the shape of 1/4 inch hexagonal rod. The drawn rod is then cut into the desired lengths and tip machined prior to subsequent processing, including heat treatment and shot blasting.

The properties of screwdriver bits are affected by three key factors: materials, heat treatment and the machining process. The influences for these three factors are shown as follows:

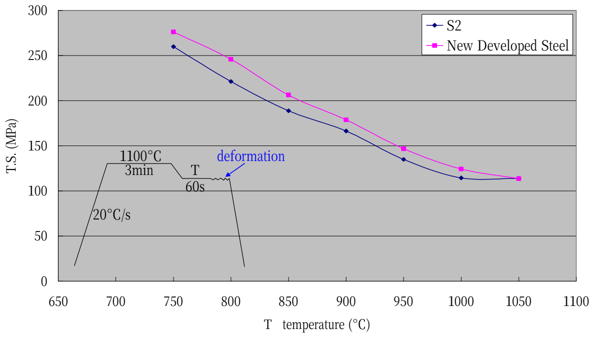

Fig. 6. High temperature deformation resistance curves for the newly developed steel and S2 steel.

3.1 Materials

The composition design of a new steel to be used for screwdriver bits is basically made with reference to the contents of SAE6150, SAE9254 and S2 steels. The reasons for adding these elements are described below:

Carbon is an element that is effective for enhancing the hardness of steel. According to past study in the CSC laboratory, the hardness of steel can not reach HRC60 when the carbon amount is just around 0.6%. If it is more than 0.7%, the torque value accompanying the lower toughness is not sufficient. Therefore, the carbon content for this new steel is set at 0.66%.

Silicon is an element that is effective in improving the strength of steel and the sag (relaxation) resistance of the spring as a solid solution element in ferrite. In this study, these effects were used for the design of the newly developed screwdriver bit steel not only to increase the hardness but also dramatically prevent the plastic deformation under torsion application. The torque value can therefore be increased as the twist angle is extended due to the higher plastic deformation resistance of steel with a higher silicon content. The torque value of a screwdriver bit made by SAE9254 steel is greater than that made by SAE6150 steel. The reason may be that the former has a higher silicon content than the latter. Hence, silicon is a crucial element for products requiring a higher torque value. For this newly developed steel, a higher silicon content is also added for the purpose of strengthening the ability of twist deformation resistance. Adverse effects, such as hard scarfing for billet and a higher decarburizing layer for wire coil, can easily appear if the silicon content is too great; therefore, it is suggested that the silicon content is limited to 2.0%.

Nickel is an element that is effective in improving the toughness of steel after the quenching hardening and tempering treating, In addition, nickel is also added to reduce the decarburizing layer. The latter effect is beneficial to reduce the drawback caused by the high silicon addition for this newly developed steel. Therefore, a small amount of nickel is added for the sake of the above-mentioned advantages.

Chromium is as effective as nickel in preventing decarburization and also as a strong carbide former comparable with molybdenum. Strong carbide formers help hard carbides form, and these carbides are beneficial to screwdriver bits in protecting them from abrasion. Chromium is much cheaper than molybdenum; hence chromium addition instead of molybdenum can reduce the cost of the necessary elements.

Vanadium is significant in the effect of refining crystal grains in the low temperature rolling and austenitization condition. Niobium also has the same effect as vanadium. From past study in the CSC laboratory, fatigue property is enhanced when the vanadium content is reduced and a small amount of niobium is added. In this trial, a small amount of niobium replaces some of the vanadium content in the newly developed steel compared with the S2 steel composition. This also reduces the element expenses.

3.2 Heat Treatment

Heat treatment by quenching and tempering is the most effective treatment for steel used for screwdriver bits. In general, it is suggested that the optimum austenitizing temperature is set at Ac3 + 30~50℃. In this trial, the optimum austenitization condition was obtained by the hardness curve of the quenching specimens from the combination of austenitizing temperature vs. austenitizing period. It can be found the hardness curves of oil quenched specimens for this newly developed steel. Fig. 7 shows that the optimum austenitizing condition should be set at about 860℃ for 15 minutes prior to oil quenching. This austenitizing temperature is only 10℃ above the Ac3 point, which is beneficial to the furnace life due to its lower temperature. If the temperature is greater than 880℃, it will be harmful to the furnace life and increase the cost of energy. Figure 8 shows the martensite morphology for the 860℃- 15 minutes oil quenched specimen by optical microscopy. The average hardness for this sample was around HRC63.3. The above-mentioned specimen was also observed by scanning electron microscopy, as shown in Fig. 9. A few undissolved carbides of size < 0.65μm can be observed in this image. These carbides are too small to identify by EDS and presumed to be (Fe, Mo, Cr) carbides. Molybdenum and chromium are two well-known strong carbide former elements, therefore it is difficult for them to dissolve entirely at the austenitizing temperature only 10℃ above the Ac3 point. These carbides, which are also used in saw tools, are useful and effective in providing abrasion-resistance in use.

Further tempering treatment was performed to achieve the desired hardness and suitable toughness. Figure 10 shows the tempering hardness vs. tempering temperature curves for this newly developed steel. A hardness of

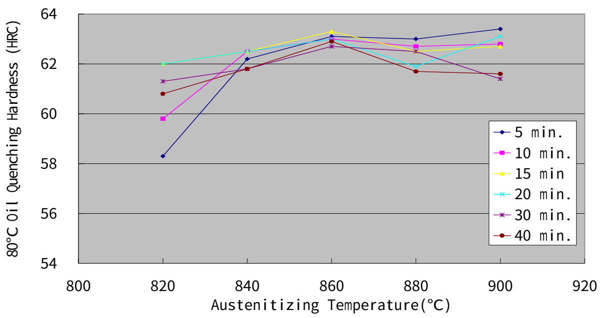

Fig. 7. Hardness curves of oil quenching specimens for the newly developed steel.

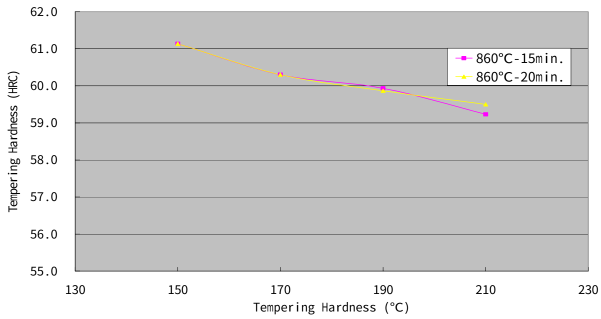

Fig. 10. Tempering hardness for different temperature.

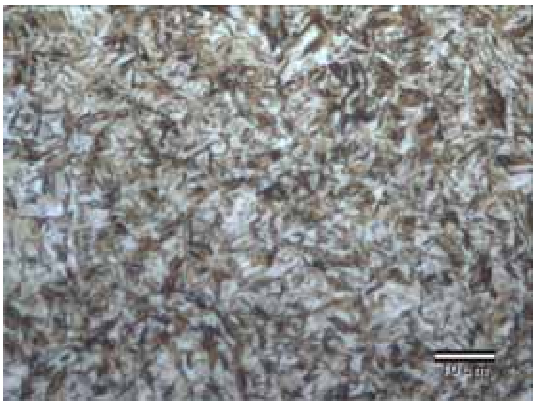

Fig.8. OM morphology for 860℃-15min. austenitizing and oil quenching specimen.

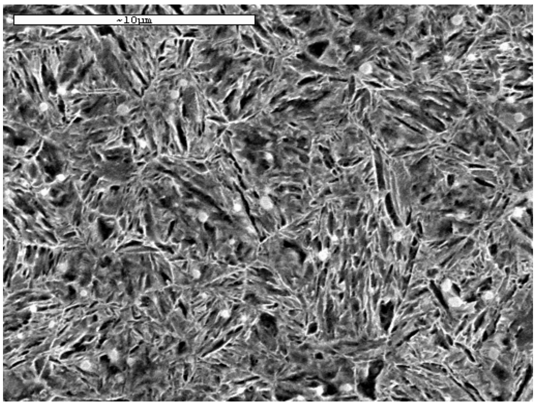

Fig. 11. SEM morphology for for oil quenching (860℃ -15min.) and tempering (170℃-2hrs) specimen.

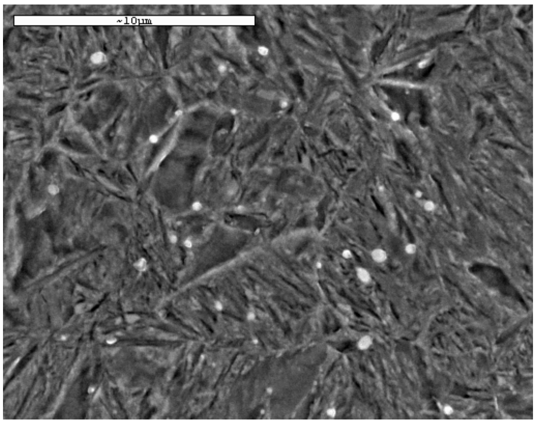

Fig. 9. SEM morphology for 860℃-15min. austenitizing and oil quenching specimen.

about HRC60.5 was obtained at a tempering temperature of 160℃. According to the diagram, the variation of tempering hardness is rather low. Even if the difference in tempering temperature is 20℃ (ex. 150℃~170℃), the variation of hardness is only less than HRC 1, which takes advantages for heat treatment control for desired hardness within a wide temperature range and shows good stability of heat treatment. Figure 11 shows the tempered martensite morphology for the 170℃-2 hrs tempered specimen. It's corresponding hardness is about HRC60.3.

3.3 Machining Process

The shape of the tip is ground by an auto grinding machine. This machining process may lead to small differences in tip contour or surface property owing to the abrasion property or vibration of the grinding tool. Such differences will affect the torque value or torsion curve by torsion test. Torque value is tested under the torque machine by the specimen in the shape specification of length 100 mm, 1/4 in. hexagon, Ph.2 tip, screw-driver bit. Ten pieces of screwdriver bits with the same heat treating condition are generally tested for torque value evaluation. The torsion curves for these testing bits, as shown in Fig. 12, were provided by Yih Cheng Factory Co., Ltd. The torque values of these bits are about 228~248 kgf·cm, while the hardness is around HRC60~HRC60.9. It is important that the brittle fracture must be avoided when the testing specimen with high hardness reaches the maximum torque value with subsequent breakage. Figure 3 reveals that these testing specimens under such a high hardness level still show toughness fracture in the breakage surface. The danger of eye damage caused by such toughness breakage must be reduced.

A newly developed steel for screwdriver bits has been cast and milled successfully in CSC. Spherical annealing wire coils with several different diameters were also offered to customers in the 3rd quarter 2009. This product will be promoted throughout the world by CSC's customers, which are OEM (Original Equipment Manufacturer) of screwdriver bits such as Yih Cheng Factory Co., Ltd. It is a good chance to make CSC's products widely known in the international market.

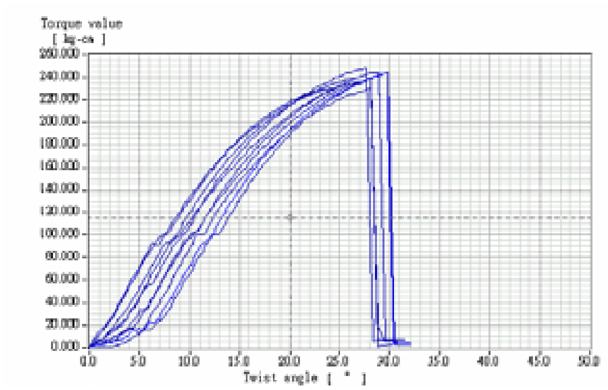

Fig. 12. Torsion curve by torsion test for the newly developed steel

4. CONCLUSIONS

In this study, a higher hardness and torque value screwdriver bit was attained by alloy redesign and suitable heat treatment. The alloy design of the newly steel was developed by the advantages extracted from the components among SAE6150 (Cr-V), SAE (Si-Cr) and S2 (Mo-V) steels. Carbon dominates the hardness but destroys the toughness. Silicon is crucial and has the effects on the solid solution strengthening and deformation-resistance. Torque value can be increased as the silicon content is higher. Nickel addition assists in compensating hard steel for toughness. Chromium combined with molybdenum to form carbides are beneficial for wear-resistance, while vanadium combined with niobium has a positive effect on grain refining hence enhancing toughness. The desired properties were obtained by heat treatment with austenitizing (860 ℃ for 15min and then oil quenching) and tempering (160℃ for 2hrs). The hardness and torque value for the screwdriver bits made by this newly developed steel are HRC60 and 228~258 kgf·cm, respectively.

REFERENCES

1. Rober Hoy: "Tool with Torque-Transmitting Working Surface and Method for the Manufacture Thereof", US. Pat. No. 5259280, Nov. 9, 1993.
2. James A. Faust, Marzell Chanton and Carl A. Shumaker: "Insert Bit for Use with a Powered Screwdriver", US. Pat. 5868047, Feb. 9, 1999.
3. Rolf Gunter Rosenhan: "Screwdriver, Screwdriver Bit or the like", US. Pat. 5953969, Sep. 21, 1999.
4. Martin Strauch: "Hand Tool, in Particular, a Screwdriver", US. Pat. 6883405 B2, Apr. 26, 2005. □